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BLACKHEART AND THE AERATION OF POTATOES IN STORAGE.

F. C. STEWART AND A. J. MIX.

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BLACKHEART AND THE AERATION OF POTATOES IN STORAGE.

F. C. STEWART AND A. J. MIX.

SUMMARY.

Present knowledge of blackheart in potatoes rests upon investigations made by Bartholomew who proved that it may result from exposure of the tubers to a temperature of 38–45° C. for 14–48 hours and is due to changes in the tissues caused by a derangement of the process of respiration.

The accidental discovery that by excluding the air from potatoes blackheart may be produced at temperatures much lower than those employed by Bartholomew led the writers to make experiments with tubers in sealed jars.

From such experiments it was learned that potatoes cannot long endure close confinement. Within a certain length of time, which varies with the temperature and quantity of air available, tubers confined in hermetically sealed jars become moist over a part or the whole of their surface. If the tubers are then exposed to the air the moist surface areas turn brown and the color of the flesh changes first from white to pink then to black (blackheart).

With a volume of air equal to the volume of the tubers a confinement of ten or twelve days is sufficient to produce the symptoms described provided the temperature is around 70° F. At a temperature of 55–60° F. about twenty days are required; and at 40° F. a still longer time — somewhere between twenty-three and forty days.

Tubers in half-full and quarter-full jars behave similarly to those in full jars except that the symptoms are slower in making their appearance.

Tubers confined in sealed jars with less than about ten times their volume of air are unable to do more than barely start sprouts. For normal sprouting about nineteen volumes of air per volume of

tubers are required. Blackheart may be expected to appear whenever the volume of air available to the tubers is less than that required for normal sprouting.

Different tubers of the same lot exhibit marked differences in susceptibility, both to blackheart and to surface discoloration. The cause of this has not been determined. It appears doubtful if the size of the tubers is an important factor.

Upon learning of the injurious effects of insufficient aeration the writers made other experiments with tubers in deep tanks to determine how deeply potatoes may be piled with safety. The data obtained are insufficient for the formulation of definite rules, but it appears that six feet should be considered the maximum depth of piling when potatoes are to be stored for several months at temperatures below 45° F. At temperatures above 50° F. the depth limit should be three feet if the potatoes are to be stored longer than three or four weeks.

Tubers suffering from insufficient aeration thru deep piling behave, in a general way, like tubers in sealed jars. They sprout feebly or not at all, become moist on the surface, discolor externally upon exposure to the air, and are often affected with blackheart internally. The principal difference is in the occurrence of rotten spots caused by fungi and bacteria. This form of injury is more common with potatoes in deep piles than with potatoes in sealed jars.

Blackheart sometimes occurs in potatoes stored out-of-doors in pits and is due, undoubtedly, to insufficient aeration. However, the experiments so far made indicate that the aeration of potatoes in unventilated pits is better than might be supposed and that the ventilation of small pits is unnecessary.

The injury resulting from insufficient aeration is due to the lack of oxygen rather than to the accumulation of carbon dioxid.

Tubers affected with blackheart produced by exposure to high temperature usually appear normal externally, while those affected with blackheart produced by exclusion of the air usually show more or less surface discoloration.

Insufficient aeration during storage does not cause spindling-sprout. It may retard sprouting temporarily, but when, subsequently, the tubers are supplied with air they sprout normally if at all. Tubers severely affected with blackheart are unfit for seed

purposes, but slightly affected tubers may be planted. If tubers are sound and normal in appearance it is unlikely that they have been injured for seed purposes by any storage conditions to which they may have been subjected.

The prevention of blackheart is a shipping problem as well as a storage problem. Blackheart often results from the overheating of potatoes during shipment in stove-heated cars.

BARTHOLOMEW'S WORK ON BLACKHEART.

Blackheart is the name proposed by Bartholomew for an abnormal condition of potato tubers in which the central portion is dark brown or black. Affected tubers may appear normal externally, but when cut open they show an area of dead, black tissue, occupying a large portion of the interior. Frequently, the trouble takes the form of a cavity lined with a thick layer of tough, dead, black tissue.

Our knowledge of the cause and nature of blackheart rests upon the investigations of Bartholomew who has published two papers on the subject.[1] On page 618 of his second paper he says: "That the production of black heart in potatoes is due to changes in the tissues caused by overheating in an atmosphere devoid of sufficient oxygen to meet the demands of the rapidly respiring potatoes can not be questioned." He found blackheart occurring among potatoes shipped long distances in stove-heated refrigerator cars and came to the conclusion that the trouble resulted from overheating in transit. While considering this a common cause he recognized that there are, also, other causes. He says:[2] "No doubt this malady may occur in potatoes at other times than during shipment. Experiments have shown that the only conditions necessary are excessive temperatures and a lack of sufficient oxygen. It is entirely possible and even probable that such conditions may exist where the potatoes have been stored in close warm cellars or in pits covered with manure."

Proof of his statement that overheating is a cause of blackheart is found in the fact that he was able to produce blackheart at will by subjecting tubers to temperatures of 38–45° C. (100–113° F.) for 14–48 hours.

[1] Bartholomew, E. T. Black heart of potatoes. *Phytopathology*, 3:180–182. 1913.
——— A pathological and physiological study of the black heart of potato tubers. *Centbl. Bakt.* etc. II. 43:609–638. 1915.

[2] *Loc. cit.*, p. 623.

Altho Bartholomew recognized that both the temperature and the oxygen supply are factors in the production of blackheart, and notwithstanding his statement [3] that, "it may be prevented in shipping, or otherwise, by proper ventilation and by keeping the potatoes in a temperature which does not exceed 35° C.", it seems he did not realize that blackheart may occur at temperatures considerably lower than 35° C. provided the supply of oxygen is scant. There is nothing in either of his papers to indicate that he succeeded in producing blackheart at a temperature lower than 38° C.

ORIGIN OF THIS INVESTIGATION.

In the spring of 1914 it was observed that some tubers enclosed for about two weeks in an air-tight glass jar had failed to sprout, and when cut they were found to be affected with blackheart. Since the temperature to which the tubers had been exposed could not have been at any time higher than about 20° C. the blackheart must have come about in a manner somewhat different from that described by Bartholomew.

A few experiments demonstrated that the air supply has an intimate relation to the occurrence of blackheart, and that a considerable volume of air is required for the well-being of potatoes. This led to further experimentation to determine how large a quantity of air is required, and what is the effect of storing potatoes in deep piles in cellars and bins and in unventilated pits and piles out-of-doors.

METHODS AND APPARATUS.

Most of the experiments were made with tubers in wide-mouthed glass museum jars having a capacity of 3500–3700 cubic centimeters (about 3.5 quarts) and provided with tight-fitting, ground-glass stoppers. A few experiments were made in smaller jars of the same kind. The jars were made air-tight by running melted paraffin or sealing-wax around the stoppers. Using tubers weighing from two to four ounces it required about four pounds of potatoes to fill one of the larger jars. In full jars the volume of the air enclosed with the tubers was equal, approximately, to the volume of the tubers. It varied from about 28 to 31 cubic centimeters for each ounce of tubers. By filling the jars only partly full other ratios were obtained.

[3] *Loc. cit.*, p. 637

For the effect of storing potatoes in deep piles use was made of tall, galvanized-iron cylinders which were open at the top but air-tight on the sides and bottom. The diameter of these cylinders was nine inches. Their hight varied from 80 to 126 inches.

One experiment was made out-of-doors with piles of potatoes which were protected from freezing by covering them with oat-straw and soil according to the usual custom.

Unfortunately, it was impossible to control the temperature except within rather wide limits,— 5 to 10° Fahr. The highest and lowest temperatures employed were about 75 and 35° F. (24 and 2° C.) respectively.

The experiments were conducted during April and May, 1914; from January to May, 1915; and from October, 1915, to May, 1916. A single variety of potato, Sir Walter Raleigh, was used thruout. In all cases, excepting the out-door pit experiment, the tubers were thoroly washed. Only perfectly sound tubers were used and they were dry when put into the jars or tanks.

BEHAVIOR OF TUBERS IN FULL, SEALED JARS AT 70° F.

When jars completely filled with tubers are hermetically sealed and exposed to a temperature of about 70° F. the following results may be expected:

No sprouts will start; and any sprouts which may have been on the tubers at the time of sealing the jars will blacken and die. Otherwise, the appearance of the tubers will be normal until about the tenth day. Then the tubers will commence to show moist areas (" sweat "). This will appear earlier on some tubers than on others. By the fifteenth day the tubers will be moist over their entire surface. If removed from the jar before the appearance of the moist areas the tubers will, usually, show no discoloration externally and, if given a chance, they will sprout normally. If removed after they have begun to sweat the tubers quickly discolor upon exposure to the air. The discoloration is a shallow, brown one which appears over well-defined areas of various extent. It may cover any part or even the whole of the surface. The bud end of the tuber appears to be particularly susceptible. The stem end portion is least susceptible. (Plate I.) In a general way the discolored areas coincide with the moist areas, but there are numerous exceptions to the rule.

After a few days' exposure to the air the discolored areas become slightly depressed and drops of a brown, sticky exudate appear here and there. Tubers having less than about half of their total surface discolored resist decay for a long time if kept dry, and may even produce sprouts; but tubers more severely affected soon decay. Besides the large discolored areas above described there often occur, also, circular, dead, brown, depressed spots two to five millimeters in diameter. These resemble considerably the spots produced by fumigation with formaldehyde gas as described in Bulletin No. 369 of this Station.

When tubers are left in the sealed jars until their entire surface becomes moist they are usually attacked by anaerobic bacteria which soften the tissue in spots under the skin. In some cases large clusters of gas bubbles appear. The odor of tubers so affected is extremely disagreeable. When exposed to the air they quickly decay. Occasionally, the tubers become moldy in the jars, but, as a rule, bacteria gain the supremacy if the jars are well filled and the temperature at 70° F. or higher. If tubers affected with this bacterial decay are permitted to remain long in a sealed jar pale-straw-colored liquid rapidly collects in the bottom until the jar is about one-half filled with it.

Blackheart may be expected to appear in any tuber which has been long enough in a sealed jar to show moist areas on the surface. Occasionally, it is found also in tubers which show no moisture while in the jar or external discoloration after exposure to the air. In general, the more severe the sweating and external discoloration the greater the severity of the blackheart.

The flesh of tubers cut immediately after removal from a sealed jar is of normal color, but after exposure to the air for a short time the central portion of the cut surface first becomes pink then gradually blackens. Tubers exposed to the air twenty-four hours or longer before cutting show blackheart immediately, if ever.

The tissue affected with blackheart is that which occupies the medullary region. In the main, it lies in the central portion of the tuber, but it is often very irregular in outline. (Plate II.) It is almost always elongated in the direction of the long axis of the tuber and, frequently, branches extend to the buds. (Plate III.) Occa-

sionally, blackheart appears in the form of large black spots scattered irregularly thru the flesh of the tuber. Sometimes it is accompanied by blackening in the vascular region. The color of affected tissue varies from gray black to coal black.

Tubers may be quite severely affected with blackheart yet sprout normally and produce normal plants. Special attention has been given to the character of the sprouts of tubers affected with blackheart. No tendency to produce spindling sprouts has been observed. If any sprouts appear they are of normal diameter.

When tubers affected with blackheart are exposed for several days to air of low humidity (e. g., that of an ordinary living room) cavities develop in them. Such cavities are often of considerable size and lined with a layer of tough, black tissue resembling rubber. Evidently, these cavities result from shrinkage of the affected tissue thru loss of water as described by Bartholomew. (Plate II.)

Smaller cavities of another kind and of a different origin are found frequently in tubers which have been enclosed in sealed jars for some time but not long enough to produce blackheart. These are usually lens-shaped, three to ten millimeters in diameter, and destitute of a black lining or flesh discoloration of any kind. Altho commonly found near the center of the tuber they may occur near one end or in the vicinity of a bud. Occasionally, two or more cavities are found in a single tuber. They occur much more frequently in small tubers than in large ones. How these cavities originate is not known to the writers, but the fact that they appear only in tubers from which air has been excluded indicates that lack of oxygen is, in some way, responsible for them. Diligent search has been made for such cavities in tubers well supplied with air, but none have ever been found. That they are not caused by shrinkage of the tissue thru loss of water is shown by the fact that they are formed while the tubers are yet in the jar and surrounded by an atmosphere heavily charged with moisture. They are found in tubers cut immediately after removal from sealed jars.

These cavities differ from those known as hollow-heart in being smaller, more regular in shape, free from discoloration of the surrounding tissue, and by occurring in small tubers rather than in large ones. They are of little economic importance.

BLACKHEART PRODUCED AT LOW TEMPERATURE.

The following experiment demonstrates that blackheart may be produced at temperatures below 43° F.:

On December 16, 1915, three glass jars filled with clean, dry, sound tubers were hermetically sealed and placed in the Station potato cellar. One of the jars was opened at the end of twenty-three days. Eight of the twelve tubers which it contained were moist on the surface. Upon exposure to the air they became discolored all over. The other four, which were dry when removed from the jar, did not discolor; but they showed a number of small pits. Eight of the tubers had small areas of blackheart.

A second jar was opened at the end of forty-one days. None of the tubers were moist, but four showed large areas of discoloration while yet in the jar and the others were somewhat pitted. All of the twelve tubers were cut immediately. Eleven of them were found to be severely affected with blackheart. One of these had, also, a cavity. The remaining tuber was normal within.

The third jar was opened at the end of fifty-eight days. All of the tubers were dark-colored externally and wet all over, but none were moldy or affected with bacterial decay. They had an odor of alcohol. All were affected with blackheart and three had, also, good-sized cavities.

The temperature of the air in the cellar during the period covered by this experiment (December 16, 1915, to March 14, 1916) is given in Table IV. The highest temperature was 42° F. and the lowest 34° F.

QUANTITY OF AIR REQUIRED FOR THE MAINTENANCE OF LIFE AND HEALTH IN POTATO TUBERS.

It having been demonstrated that tubers in full, sealed jars soon die and decay the question arose as to how large a volume of air is required for the maintenance of life and health in potato tubers.

It is a well-known fact of plant physiology that potato tubers require a certain amount of air. So long as they live they must respire; that is, they consume oxygen and give off carbon dioxid and water. Their source of oxygen is the air. Hence, they must have a constant supply of air. It is known, also, that, within certain limits, the rapidity of respiration increases with rise in temperature.

At a temperature of 70° F. potato tubers respire more rapidly, consume more oxygen and hence require more air than at a temperature of 50° F. Likewise, more air is required at 50° F. than at 35° F.[4]

Lacking means of controlling the temperature accurately the writers have been unable to secure experimental data which would enable them to give a wholly satisfactory answer to the question here raised. However, it seems worth while to record some of the results obtained in the experiments.

From the results of a few experiments with half-full and quarter-full jars it appears that with these larger quantities of air the tubers behave in practically the same way as tubers in full jars except that the symptoms of blackheart and decay are slower in making their appearance.

AN EXPERIMENT WITH A HALF-FULL TANK AND A HALF-FULL JAR.

In February, 1916, the following experiment was made: A cylindrical, galvanized-iron tank nine inches in diameter and eighty inches deep was half filled with potato tubers (244 tubers weighing 56.5 pounds) and the tank hermetically sealed by means of a tight-fitting cover overrun with melted paraffin. The potatoes were taken from a cellar where they had been in storage at a temperature of 36–42° F. They were washed and thoroly dried before being placed in the tank. Only perfectly sound tubers were used. No sprouts had started on any of them.

At the same time a glass jar (capacity 3.5 quarts) was half filled with some of the same lot of tubers and sealed. This was to be used as an indicator to determine the proper time for opening the tank. A second glass jar of the same kind was completely filled with tubers and sealed. The tank and pair of glass jars were placed in a partially darkened room the temperature of which was recorded once a day. Owing to the temperature being rather low, 13–16° C.,

[4] Ziegenbein (*Jahrb. Wiss. Bot.* [Pringsheim] 25:594. 1893.) has determined the rapidity of respiration of potato tubers at different temperatures by measuring the quantity of carbon dioxid produced by a given weight of tubers in a given length of time. His results are stated in milligrams of carbon dioxid produced by 100 grams of tubers in one hour. They are as follows:

Temp.	CO_2	Temp.	CO_2	Temp.	CO_2
Deg. C.	*Mg.*	*Deg. C.*	*Mg.*	*Deg. C.*	*Mg.*
10	1.17	35	7.85	50	11.14
20	2.22	40	10.24	55	10.30
30	4.62	45	12.22	60	2.71

tubers. (See Table I.) The tubers used were clean, sound and dry and had not begun to sprout. The experiment was begun on March 10, 1916, at which time the jars were sealed with paraffin and placed in a partially darkened room. The check consisted of twenty tubers in an open jar. During the course of the experiment the temperature fluctuated between 15° and 22° C.

TABLE I.— QUANTITY OF AIR REQUIRED FOR MAINTENANCE OF LIFE IN POTATO TUBERS: FIRST SERIES OF EXPERIMENTS.

JAR.	Number of tubers.	Total wt. of tubers.	Total quantity of air.	Number of volumes of air per volume of tubers.*	CONDITION AT END OF 40 DAYS.	
					Sprouts	Blackheart.
		Oz.	*Cc.*			
I	7	24	2,940	4.6	Barely started; dead.	Present.
II	5	20	3,070	5.8	Barely started; dead.	Present.
III	4	16	3,105	7.4	Barely started; dead.	Present.
IV	3	14	3,190	8.6	Barely started; dead.	Present.
V	3	12	3,310	10.5	Very feeble; dead†	Present.
VI	3	11	3,330	11.5	Very feeble; dead.	Present.
VII	2	10	3,350	12.7	Very feeble; dead.	Present.
VIII	2	9	3,490	14.7	Very feeble; dead.	Present.
IX	2	8	3,320	15.7	Feeble; d ad	Present.
X	2	7	3,410	18.5	Feeble; dead	Present.
XI	2	6	3,520	22.2	Normal	Present.
XII	2	5	3,550	26.9	Normal	Absent.
XIII	1	4	3,500	33.2	Normal	Absent.

* For the method by which the ratios given in this column were computed, see the footnote on page 331.

† It appears that Jar V was not perfectly air-tight.

The condition of the tubers in the several jars was carefully noted and compared with the check at the end of thirteen, eighteen, twenty-five, thirty-six and forty days.

Sprouts started in all of the jars. With 8.6 volumes or less of air (Jars I–IV) the sprouts were not, at any time, more than barely visible. Some of them remained alive at the end of eighteen days, but all were dead at twenty-five days. In Jars VI–VIII, containing 11.5 to 14.5 volumes of air, sprouts started freely, attained a length of one-fourth inch and lived upwards of twenty-five days; but they were distinctly less robust than the sprouts on check tubers and were either dead or dying at the tips by the end of thirty-six days. In Jars IX–X, containing 15.7 and 18.5 volumes of air, the sprouting of the tubers appeared normal for about eighteen days. At the end of twenty-five days the sprouts were about one-half inch in length when sprouts on the check tubers were from one-half to three-fourths of an inch long. At thirty-six days they were dying at the tips. In Jars XI–XIII, containing 22.2 to 33.2 volumes of air, the sprouts were considerably longer than those on the check tubers, but somewhat less robust, owing, presumably, to the greater humidity of the air in the sealed jars. So far as sprouting is concerned there was no indication that the tubers in these jars suffered from lack of air.

In some of the jars the tubers became damp on the surface, but they did not show distinct moist areas such as appear on tubers in full jars.

In Jars I and IV, containing 4.6 and 8.6 volumes of air, the tubers became quite moldy after twenty-five days of confinement; but in Jars II and III, containing 5.8 and 7.4 volumes of air, there were only traces of mold. The cause of this difference in moldiness is not known. The mold appeared in conspicuous whitish tufts, chiefly at the eyes. It was not identified.

At the end of forty days the jars were all opened and the tubers immediately cut and examined for blackheart. All three tubers in Jar V showed a cavity surrounded by blackheart when first cut. This is considered proof that the jar had leaked air, as had been suspected from the sprouting of the tubers. The tubers in Jar XII (with 26.9 volumes of air) and Jar XIII (with 33.2 volumes of air) showed no indication of blackheart even after exposure to the air. In all other jars the tubers were white inside when first cut, but after exposure to the air for a short time all developed pinkheart, which, in the course of a few hours more, became typical blackheart.

SECOND SERIES OF EXPERIMENTS WITH PARTLY-FULL JARS.

A second series of experiments with partly-full jars included eleven jars of potatoes in which the number of volumes of air per volume of potato tubers varied from 9.2 to 22.1. (See Table II.) This series was started April 21 and continued for twenty-six days, during which time the temperature ranged from 20 to 23.5° C. Very small sprouts were showing when the tubers were placed in the jars.

TABLE II.— QUANTITY OF AIR REQUIRED FOR MAINTENANCE OF LIFE IN POTATOES: SECOND SERIES OF EXPERIMENTS.

JAR.	Number of tubers.	Total wt. of tubers.	Total quantity of air.	Number of volumes of air per volume of tubers.*	Condition of sprouts at end of 26 days.
		Oz.	*Cc.*		
I	4	14	3,390	9.2	Barely started; dead.
II	3	13	3,200	9.3	Barely started; dead.
III	3	13	3,250	9.5	Barely started; dead.
IV	2	10	3,320	12.6	.75 in. long; dead at tips.
V	2	10	3,450	13.1	.75 in. long; dead at tips.
VI	2	7	3,390	18.4	1–1.25 in. long; brown at tips.
VII	2	7	3,400	18.4	1–1.25 in. long; brown at tips.
VIII	2	6.5	3,375	19.7	1.25–1.5 in. long; normal.
IX	2	6.5	3,425	20.	1.25–1.5 in. long; normal.
X	2	6	3,485	22.	1.25–1.5 in. long; normal.
XI	2	6	3,500	22.1	1.25–1.5 in. long; normal.

* For the method by which the ratios given in this column were computed, see the footnote on page 331.

Tubers having 9.5 volumes or less of air (Jars I–III) barely started sprouts which all died within about twenty days. On tubers having 12.6 and 13.1 volumes of air (Jars IV and V) the sprouts attained a length of over three-fourths of an inch, but they were

less robust than the sprouts on check tubers and began to wither at the tips by the end of twenty days. The sprouting of tubers having 18.4 volumes of air (Jars VI and VII) appeared to be normal at twenty days, but at twenty-six days the sprouts had begun to turn brown at the tips. In the remaining four jars (VIII–XI), with 19.7 to 22.1 volumes of air, the sprouting was normal and there was no external evidence of injury up to the end of twenty-six days, when the experiment was closed.

As happened in the first series, the sprouts on tubers having a large volume of air were considerably longer than the sprouts on check tubers, but they were not so stout. For example, at the end of twenty days, in Jars VI–IX, with 18.4 to 22.1 volumes of air, the larger sprouts measured from one to one and one-fourth inches, while the sprouts on check tubers were only three-fourths of an inch long. The greater length of sprouts in the sealed jars is to be attributed to the greater humidity of the air in which they were formed.

No observations were made on the condition of the tubers as regards blackheart.

RELATIVE RESISTANCE OF LARGE AND SMALL TUBERS.

According to Hoffman and Sokolowski [6] small tubers respire more rapidly, volume for volume, than large ones. This being true, it seems as if a scarcity of air should be less injurious to large tubers than to small ones. Two experiments were made in an attempt to demonstrate this experimentally.

In the first experiment four glass museum jars (capacity about 3700 cc.) were completely filled with tubers of different sizes and kept hermetically sealed for a period of sixteen days at a temperature of 57–70° F. In each jar the tubers were fairly uniform in size. Jar I contained 42 tubers having an average weight of 49.3 grams; Jar II, 26 tubers with an average weight of 81.8 grams; Jar III, 26 tubers with an average weight of 100.3 grams; and Jar IV, six tubers with an average weight of 293 grams. By putting small stones into some of the jars the ratio of air to tubers was made uniform in all four jars, viz., 22.5 cc. of air to each ounce of tubers, or .85 of a volume of air per volume of tubers.

[6] Abstract in *Exp. Sta. Rec.* 24:541. 1911.

When the jars were opened at the end of sixteen days the condition of the tubers in Jars I–III appeared quite similar. All were quite damp and foul-smelling, tho of normal color and sound, with the exception of two tubers, each of which had a small bacterial soft-rot spot. No sprouts had started. Sixteen hours after removal all tubers were showing large areas of discoloration occupying one-fourth to three-fourths of their entire surface, the tubers in all three jars being about equally affected on the average. Subsequent observations showed that none of the tubers were capable of sprouting and about one-half of the total number were affected with blackheart.

The large tubers in Jar IV were affected quite differently. They were dry when the jar was opened, did not smell bad, and upon exposure to the air they did not discolor over large areas, but, instead, became covered with small, sunken, dead, brown spots similar to those which result from fumigation with formaldehyde gas.[7] Altho most of the spots were less than one-fourth inch in diameter and few of the eyes were affected, the spots were so numerous that the tubers were severely injured. Nevertheless, five of them sprouted fairly well, producing short, thick sprouts. After eighteen days' exposure to the air five of the tubers were cut. One was normal within, but in each of the other four there was a large cavity lined with a layer of dead, black tissue — typical blackheart in the late stage.

In the second experiment six jars were used. Jars A and B were filled with small tubers having an average weight of 69 grams in A and 84 grams in B; Jars C and D with large tubers having an average weight of 288 grams in C and 349 grams in D; Jar E with one large tuber weighing 340 grams and nineteen small ones having an average weight of 78 grams; and Jar F with one large tuber weighing 326 grams and eighteen small ones having an average weight of 83 grams. The ratio of air to tubers was made uniform in all six jars, viz., 28.62 cc. of air to each ounce of tubers or 1.1 volumes of air per volume of tubers.

The temperature being somewhat higher, the tubers began to show signs of injury earlier than in the preceding experiment. The jars were opened at the end of twelve days. While the appearance of the tubers in the several jars varied considerably the differences

[7] See Bulletin 369 of this Station.

could not be ascribed to differences in the size of the tubers. The large tubers in Jar D were as severely injured as the small tubers in Jars A and B and in the same manner. They were damp and free from mold when first removed from the jars, and showed large areas of discoloration upon exposure to the air. On the other hand, the large tubers in Jar C were dry and somewhat moldy when taken from the jar, and upon exposure to the air developed sunken, brown spots as if injured by formaldehyde gas. The large tuber in Jar E was quite as severely injured as the small tubers in the same jar and in the same manner. All had large areas of surface discoloration. On the other hand, the tubers in Jar F, both large and small ones, showed considerably less surface discoloration and more spotting of the gas-injury type. Some of the small tubers in Jar F were no more injured than the large tuber in that jar.

None of the tubers in any of the jars were able to sprout. All of them were more or less affected with blackheart, but there were no differences in this respect worthy of mention.

While the first of these experiments indicates that large tubers are more resistant to asphyxia than are small ones, the second experiment leaves this in doubt and suggests that some other character or condition of the tubers is more important than size.

The view that the size of a tuber is less important than some other character in determining its susceptibility to injury from an insufficient supply of air is supported by the observation that when tubers of mixed sizes are confined in sealed jars some tubers are affected much earlier and injured more severely than others, and the size of the tubers appears to bear no relation to the earliness or severity of the injury. This has been observed in many of the experiments. With respect both to blackheart and surface discoloration there is marked individuality among tubers, but the explanation of it is not known.

DEEP PILING OF POTATOES IN STORAGE: EXPERIMENTS WITH POTATOES IN DEEP CYLINDRICAL TANKS.

In storage cellars potatoes are often piled to a depth of several feet without any provision being made for ventilation. Having learned from the experiments with sealed jars that potatoes require a considerable amount of air it became of interest to the writers

to know how deeply potatoes may be piled without danger of injury from asphyxiation. It seems as if the small amount of air available to tubers at the bottoms of deep piles might be insufficient for the requirements of respiration, particularly if the temperature is high.

Information on this point was sought from experiments in which potatoes were piled to depths of 6.5 to 10.5 feet in cylindrical, galvanized-iron tanks which were air-tight on the bottom and sides but wide open at the top. The diameter of these tanks was nine inches in all cases, but the hight varied from 80 to 126 inches. How the aeration of tubers in these tanks compares with that of tubers at an equal depth in large piles and bins is not fully known. Certainly, the aeration was no better in the tanks than in piles; because in the tanks air could reach the tubers only from the top while in piles there must be some circulation of air on the sides as well as from the surface. However, when it is considered that the air which tubers in piles receive from the side has been robbed of most or all of its oxygen by neighboring tubers it appears improbable that such air is of much value. Accordingly, there is reason to believe that the behavior of tubers in the tanks represents fairly well the behavior of tubers in piles at a similar depth.

FIRST TANK EXPERIMENT.

In the first of these tank experiments a single tank eighty inches deep was used. It was filled and the experiment begun on February 16, 1915. As the potatoes were being put into the tank pieces of wire screen were inserted at depths of 54 and 27 inches to divide the contents of the tank into three parts. The tank was placed in an unheated interior room of an office building where the humidity of the air was low and the temperature 18–21° C. most of the time.

On April 27, at the end of seventy days, the potatoes were taken out of the tank. Altho the tank was more than even full at the beginning of the experiment the uppermost tubers were now seven or eight inches below the top of the tank. Tubers on top were somewhat shriveled. They had sprouts one to two inches long. (Plate V, fig. 1.) At a depth of two feet the tubers were sprouting vigorously. Some sprouts were short and much branched; others three to four inches long and club-shaped. (Plate V, fig. 2.) All of the sprouts, excepting those on tubers near the top of the tank, were covered with a conspicuous eruption of enlarged lenticels.

Down to the first division screen (depth of 27 inches) the tubers were dry, free from mold and decay, sprouting normally and the sprouts all alive. When cut, none of the tubers were found affected with blackheart or other internal discoloration. Two had hollow-heart, but no cavities were found like those described on page 327.

As soon as the first screen was passed the tubers began to be damp and moldy and the sprouts to show signs of decay. The prevalence of moisture, mold and decay increased rapidly until by the time the second division screen was reached (at the depth of 54 inches) many tubers were ruined. (Plate VI, fig. 2.) When the tubers were cut no case of blackheart was found. A few tubers showed some blackening in the vascular region and one had a lens-shaped cavity.

Below the second screen, at a depth of 54 to 80 inches, the tubers were all ruined. A few at the very bottom had barely started sprouts. (Plate VI, fig. 1), but most of the tubers had produced robust sprouts which afterward decayed. There were no indications of spindling sprouts. All of the tubers were very wet and there was about a pint of foul-smelling liquid in the bottom of the tank. Upon exposure to the air the tubers became discolored on the surface like tubers from sealed jars. When cut, about fifty per ct. of the tubers showed pronounced blackening in the vascular region, a considerable number had small cavities like those described on page 327 and some were affected with blackheart. Both blackheart and cavity formation were usually accompanied by fibro-vascular blackening.

While this experiment demonstrates insufficient aeration of the tubers in the lower part of the tank the effect on the tubers was not quite what was expected. There was less blackheart and much more fibro-vascular blackening. Neither before nor since have we observed so much fibro-vascular blackening to result from insufficient aeration.

SECOND TANK EXPERIMENT.

A second tank experiment was started on April 29, 1915, using the same tank as in the first experiment after disinfection with formaldehyde solution. It being desired to ascertain the temperature of the tubers within the tank a glass tube one-half inch in diameter and eighty inches long was placed in the center of the tank and the tubers filled in around it. When the tank was completely filled the glass tube was raised a few inches and a thermometer attached to a string was lowered thru the tube until its bulb rested

among the tubers five inches from the bottom of the tank. The upper end of the tube was kept closed with a rubber stopper except for short intervals twice a day when the thermometer was drawn up for reading. A second thermometer, previously compared with the first, was hung in the air on the outside of the tank five inches above the floor.

In the fifteen days during which the experiment was conducted the thermometers were read 25 times. In fourteen readings the thermometer inside the tank stood higher than the one on the outside, but in no case was the difference greater than 1° C. In the other eleven readings the two thermometers agreed. The highest temperature recorded was 25° C.; the lowest, 19° C.

From this it appears that the temperature inside the tanks in these experiments is but slightly higher than that of the surrounding air. The injury to the tubers is not due to overheating.

The potatoes were removed from the tank on April 14 at the end of fifteen days. Tubers near the top had sprouts about three-fourths of an inch long. The maximum vigor of sprouting had occurred, as in the first experiment, at a depth of 24–27 inches. Here, most of the sprouts were an inch long. (Plate VII, fig. 1.) Tubers in the bottom of the tank were only slightly damp, free from mold and apparently sound; but the sprouts were barely started and in the same condition as at the beginning of the experiment. (Plate VII, fig. 2.) It was plain that sprouting had been checked by lack of air. Altho apparently sound when removed from the tank, these tubers within a few days developed rotten spots of quite large size and extending deeply into the flesh. Some which were given an opportunity to sprout produced normal sprouts. None of the tubers were affected with blackheart.

Tubers in a full sealed jar, but in other respects under conditions parallel with those in the tank, were dead at the end of seven days. Upon exposure to the air they discolored badly, became affected with blackheart and were unable to sprout.

THIRD TANK EXPERIMENT.

A third experiment with the 80-inch tank was begun October 4, 1915, and closed October 28. The potatoes used in this experiment had been out of the ground only two weeks and so had not completed their rest period. Accordingly, it was not expected that they would

sprout; and, as a matter of fact, they showed no sign of sprouting at the end of 24 days notwithstanding the temperature was sufficiently high (15–19.5° C.) to induce sprouting had the tubers been capable of it. Tubers in the bottom of the tank were slightly moist, but showed no discoloration (either internal or external) or any other indication of injury.

FOURTH TANK EXPERIMENT.

In the fourth experiment the potatoes were put into the tanks November 8, 1915, and taken out January 6, 1916, at the end of 59 days. Three tanks were used — two 80 inches deep and one 107 inches deep. The experiment was conducted in the same room as the previous experiments.[8] The ceiling, being only 109 inches from the floor, was barely high enough to admit the tall tank.

The tall tank was divided into four sections by wire screens placed at depths of 81, 54, and 27 inches, the object being to make it possible to keep the tubers from different parts of the tank separate while removing them from the tank. Similarly, the shorter tanks were divided into three sections each. In both of the 80-inch tanks glass tubes were installed for the insertion of thermometers as in the second experiment. One of the 80-inch tanks was set in a wooden box 18 inches square by 82 inches deep and the space between the tank and walls of the box filled with sawdust to secure insulation.

Four thermometers were used — one inside the insulated tank with its bulb four inches from the bottom; one in the same position on the inside of the uninsulated 80-inch tank; another outside the tanks four inches above the floor; and the fourth outside the tanks ten inches below the ceiling. Parallel readings of the four thermometers were made daily. Twenty-three of these readings were made at 8 A. M., eighteen at 1 P. M. and seventeen at 5 P. M.

Table III gives the maximum and minimum temperatures recorded by each of the four thermometers at 8 A. M., 1 P. M. and 5 P. M.; also, the average temperature at each of these hours. From an

[8] The room in which these experiments were conducted is one formerly used for experiments on the curing of cheese. It was built expressly for that purpose and constructed in such a way as to facilitate the maintenance of a constant temperature. At first it was equipped with an automatic device for regulating the temperature, but at the time of our experiments this was not in operation. The room is an unheated interior one, 10x10x9 feet, with a single double-glass window in the upper part of the door. The walls, floor and ceiling are thoroly insulated. The door, also, is insulated and fits very closely.

examination of this table it will be seen that the average temperature inside the two tanks differed but slightly from that of the air of the room at the same distance above the floor. This confirms the conclusion deduced from the second tank experiment, viz., that the injury to tubers in the tanks is not due to overheating. That heat is evolved in the process of respiration is a well-established fact; but the amount of heat resulting from the respiration of potatoes is, seemingly, too small to materially affect their keeping qualities. This is shown by the fact that the average temperature within the insulated tank was practically the same as that of the surrounding air. However, it must be admitted that differences in the condition of the tubers in different tanks in this experiment, about to be described, indicate that a slight rise in temperature continued for a long time may have important effects.

TABLE III.—SUMMARY OF TEMPERATURE CONDITIONS AFFECTING POTATOES IN TANKS: FOURTH EXPERIMENT.

LOCATION OF THERMOMETER.	MAXIMUM AND MINIMUM TEMPERATURES.						AVERAGE TEMPERATURE.		
	8 A. M.		1 P. M.		5 P. M.				
	Max.	Min.	Max.	Min.	Max.	Min.	8 A. M.	1 P. M.	5 P. M.
	Deg. C.	*Deg. C.*	*Deg. C.*	*Deg. C.*	*Deg. C.*	*Deg. C.*	*Deg. C.*	*Deg. C.*	*Deg. C.*
Inside insulated tank near bottom.....	19	15.5	19	15.5	18.5	15	16.6	16.6	16.7
Inside uninsulated tank near bottom.	19.5	14	19	14.5	19	14	16.2	16.3	16.5
Outside the tanks near floor.....	20	14	20	14	20	14	16.2	16.6	16.9
Outside the tanks near ceiling.....	20	14.5	20.5	14	20.5	15	16.6	17.7	17.6

At the end of 59 days the potatoes were removed from the tanks. In describing the results of the experiment the portion of each tank above the upper division screen will be designated as Section 1; that between the upper screen and the next one below, as Section 2; and so on to the bottom of the tank.

The two outstanding features of the experiment were: (1) The sprouts on the tubers in Section 1 of the uninsulated tank were noticeably shorter than the sprouts on tubers in the corresponding section of the other two tanks; (2) tubers in Section 3 of the tall tank were sprouted less and were considerably more affected with rot than tubers in the corresponding section of the two 80-inch tanks.

A third feature, less conspicuous yet worthy of note, was the better condition of the tubers in Section 3 of the uninsulated tank as compared with that of tubers in Section 3 of the insulated tank.

In Section 1 of the uninsulated tank the longer sprouts were one-half to two-thirds of an inch long, while those in Section 1 of the other two tanks were about twice this length. (Plate VIII.)

In Section 3 of the tall tank no sprouts had started. Many tubers had sunken rotten spots or areas of brown discoloration accompanied by softening of the tissue. In Section 3 of both short tanks the tubers had begun to sprout some and several had rotten spots; but on the whole the condition of the tubers was considerably better than that of tubers in Section 3 of the tall tank.

It is hard to believe that the slightly higher temperature in the insulated tank can have been responsible for the greater length of the sprouts in Section 1 as compared with those in the corresponding section of the uninsulated tank; but there seems to be no other satisfactory explanation for it. Likewise, there appears to be no other explanation for the better condition of the tubers in the uninsulated tank.

The greater length of sprouts in the upper section of the tall tank may be attributed to the fact that the tubers were nearer the ceiling where the temperature was slightly higher.

As regards the better condition of the tubers in Section 3 of the short tanks as compared with those in Section 3 of the tall tank the only plausible explanation appears to be that the daily raising and lowering of the thermometers thru the glass tubes in the short tanks permitted the access of a small amount of air giving the tubers in these tanks slightly better aeration.

The tubers in Section 4 of the tall tank (at a depth of 81–107 inches) were in bad condition. Many were affected with a brown soft rot, some were moldy and others were discolored. Upon exposure to the air at a temperature of 70° F. for two weeks over two-thirds of the tubers either decayed or developed large rotten areas; but none were affected with blackheart, and those which did not decay produced normal sprouts.

FIFTH TANK EXPERIMENT.

A fifth tank experiment was begun January 15, 1916. It consisted of an 80-inch tank (A) insulated by packing sawdust around

it as in the preceding experiment, an uninsulated 80-inch tank (B), an uninsulated 107-inch tank (C), an 80-inch tank (D) hermetically sealed, and three large glass museum jars hermetically sealed. All were filled with clean, dry, sound potatoes. By means of wire screens each of the 80-inch tanks was divided into three sections and the tall tank into four sections as in the fourth experiment. The experiment was conducted in the same room as previous ones. The temperature of the room was taken, near the floor and near the ceiling, at least once a day and sometimes oftener. Thirty-five readings, made about 8 A. M., showed an average temperature of 14.5° C. at the floor and 15.4° C. at the ceiling. Twenty-three readings, made about 1 P. M., averaged 15.3° C. at the floor and 16.2° C. at the ceiling. Fifteen readings, made about 5 P. M., averaged 15° C. at the floor and 16.3° C. at the ceiling. The minimum floor temperature was 11° C.; the maximum ceiling temperature 22° C. Accordingly, the temperature averaged a little lower in this experiment than in the preceding one.

The tubers in the sealed jars were used as indicators to determine the proper time to open the sealed tank D. The ratio of air to tubers in these jars was not determined; but judging from previous determinations it must have been slightly over one volume of air per volume of tubers. In two of the jars the tubers behaved in the usual manner. One was opened at the end of fourteen days, the other at sixteen days. The tubers were quite damp when first removed. A few hours' exposure to the air caused them to discolor badly on the surface and, when cut, they were found affected with blackheart. The tubers in the third jar behaved somewhat differently.[9] They were much freer from moisture. When removed at the end of seventeen days only twelve of them were slightly damp; the other ten were dry. None of the twenty-two discolored externally upon exposure to the air. Nevertheless, all of the tubers but one developed pronounced cases of blackheart. Altho wholly destitute of sprouts at the time of their removal from the jar, the tubers afterward developed normally robust sprouts.

Tank D was provided with a cover which fitted closely into the upper end with its upper surface one-fourth inch below the level of the rim of the tank. A narrow flange on the inside of the tank

[9] It is possible that this jar was not perfectly air-tight.

prevented the cover from slipping down. Melted paraffin was run over the cover to a depth of one-fourth inch to make it air-tight. The tank contained 550 tubers weighing 113 pounds. The volume of the air among the potatoes was measured and found to be 37.5 liters, which is 20.74 cc. per ounce of tubers, or .78 of a volume of air per volume of tubers.

Tank D was opened at the end of sixteen days. The condition of the tubers was similar to that of tubers in the glass jar opened at the same time. An interesting feature was the greater injury to tubers in the bottom of the tank. Upon taking the tubers from the tank it was noticed that the dampness of the tubers increased from the top of the tank downward. A large majority of the tubers in the upper section were moist over only a part of their surface. A few were moist all over and a few were dry all over. In Section 3 many tubers were moist all over. A considerable number had dry spots, but it is doubtful if there were any which were dry all over. However, there was no free liquid in the bottom of the tank. Neither were any of the tubers moldy or rotten. Upon exposure to the air the tubers from Section 3 showed considerably more surface discoloration than did the tubers from Section 1. In Section 3 tubers wholly free from surface discoloration were rare, while in Section 1 such tubers were frequent. Tubers from Section 2 were in an intermediate condition as regards both dampness and surface discoloration. Blackheart was general and in a majority of the tubers it was severe. (Plate III.) Only eight of the 550 tubers were entirely free from blackheart. The severity of the blackheart was but slightly greater in Section 3 than in Section 1.

If the cover of Tank D were not air-tight the lesser degree of injury in Section 1 would be accounted for; but there is nothing to indicate that the cover did not fit perfectly air-tight. The tubers were affected in the same manner and as severely as those in an air-tight jar under parallel conditions. Presumably, the carbon dioxid gas produced in respiration accumulated in the bottom of the tank. This may have been responsible. Perhaps, the accumulation of CO_2 brought about earlier and more complete oxygen starvation in this part of the tank. The only other respect in which Section 3 differed from Section 1 was in the matter of temperature. Section 3, being nearer the floor, was slightly cooler; but the effect of lower temperature would be to lessen the injury, not to increase it.

The other three tanks, A, B and C, were opened at the end of sixty-two days. The tubers in Sections 1, 2 and 3 of the insulated Tank A were in almost exactly the same condition as the tubers in corresponding sections of the uninsulated tall Tank C, which will be described presently. Apparently, the insulation of Tank A had no influence.

Finding the tubers in the bottom of Tank B (uninsulated) sprouting as vigorously as those in the upper section led us to suspect that this tank leaked near the bottom. By filling the tank with water this suspicion was confirmed. Hence, the results of Tank B are of no value except to prove that it is lack of air rather than lower temperature which prevented the sprouting of tubers in the lower portion of Tanks A and C.

The condition of the tubers in the tall Tank C was as follows: Thruout Section 1 the sprouts were 1.5–5 inches long. Many were 3–5 inches long. In the upper half of Section 2 the sprouts were as long as those in Section 1, but in the lower half they were considerably shorter. In the upper half of Section 3 scarcely any sprouts were more than one-half inch long; while in the lower part of this section the sprouts had barely started. In Section 4, also, the sprouts were barely started.

The great differences in the sprouting of tubers at different depths in the tall tank are strikingly shown in Plates IX and X. Plate IX, fig. 1, shows the length and the character of the sprouts near the surface of the upper section. The sprouts are thickly covered with short hairs. The sprouts shown in Plate IX, fig. 2, are from tubers in the upper part of Section 2, at a depth of about 27 inches. Plate X, fig. 1, shows the character of the sprouts at a depth of 54 inches, and Plate X, fig. 2, shows the sproutless condition of tubers at a depth of 80–107 inches. Notwithstanding that the temperature was lower in this experiment than in the preceding one, the tubers produced much longer sprouts in practically the same length of time, owing, probably, to the longer period of rest which the tubers had had at the time the experiment was begun.

In all four sections some of the tubers were slightly moist when first taken out, but none were moldy or rotten. At the time, it was thought that the tubers in the bottom section had suffered no injury, but after a few days' exposure to the air some of them developed sunken, rotten spots which appeared to be a result of their confine-

ment. However, none were affected with blackheart. It is worthy of note that one-half bushel of tubers from the bottom section which were set aside to sprout produced normally robust sprouts. So long as they were confined in the tank at a depth of 80–107 inches they were unable to start sprouts, but when removed from the tank and supplied with air they proceeded to sprout in a perfectly normal manner.

A comparison of the condition of the tubers in the sealed Tank D with that of tubers in the bottom of the tall Tank C leads to the conclusion that there must be considerable circulation of air among potatoes at a depth of seven to nine feet. Tubers in the sealed tank were ruined by suffocation in sixteen days, while tubers in the bottom of the unsealed tank were alive and in fairly good condition at the end of sixty-two days. Meanwhile, the temperature was comparatively high, so that the tubers must have respired quite rapidly.

SIXTH TANK EXPERIMENT.

In the sixth tank experiment only two containers were used — one 107 inches and the other 126 inches deep (or tall). The 107-inch tank was the " tall " tank used in the fourth and fifth experiments. The 126-inch tank was a new one. On account of the height of the taller tank it was necessary to conduct this experiment in a basement room having a high ceiling. The tanks were filled and the experiment begun March 24, 1916. As in previous experiments, pieces of wire screen were used to divide the contents of the tanks into sections about 27 inches long.[10] The tubers used were clean, dry and sound and had not begun to sprout. The temperature was taken at two points — 18 inches below the top of the taller tank and six inches above its base. Thirty-eight daily readings averaged 16° C. for the lower point and 21.6° C. for the upper one. The maximum temperature of 25° C. was registered on the last day of the experiment.

The tubers were removed from the tanks on May 9, at the end of forty-six days. The condition of tubers in corresponding sections of the two tanks varied somewhat owing, probably, to differences in temperature; but the variation is so small that it is unnecessary to give the details for both tanks. It will be sufficient to describe the contents of the 126-inch tank.

[10] The upper section in the taller tank was only 18 inches long.

Thruout Section 1 the sprouts were about an inch long. There was no mold or indication of decay. Tubers near the top were somewhat shriveled. None of the tubers had blackheart or internal cavities.

In the upper part of Section 2, at a depth of about 2 feet, the longest sprouts in the tank were found. They measured 1–3 inches. Many of them had begun to decay. In the lower part of Section 2, at a depth of 45 inches, the sprouts were only one-fourth to one-half inch long. The tubers were slightly moist. Of twenty-five tubers which were cut immediately, all except two were normal within. These two, after exposure to the air, showed a little blackheart. After twenty-four hours' exposure to the air a few of the remaining tubers showed rotten spots, but the great majority appeared normal. Upon cutting, two were found to contain cavities and three had blackheart.

In Section 3 some of the tubers had started no sprouts; others had produced short sprouts which had afterward decayed. The tubers in this section were characterized by their moldiness. Almost every tuber was covered with white mold which had attacked the eyes, causing a kind of eye-rot. The tubers were a little moist but not wet. There was no disagreeable odor. Of twenty-five, cut immediately, seven had large cavities narrowly lined with black tissue. After exposure to the air these developed blackheart. Eleven of the twenty-five appeared normal when first cut, but later they developed blackheart. The other seven had no cavities and showed little or no blackheart, even after exposure to the air. Most of these tubers came from a depth of about 72 inches.

After exposure to the air for twenty-four hours only a few of the remaining tubers were free from discoloration and blemishes. Several had large rotten spots and nearly all had sunken areas of dead tissue around the eyes. Sixty-six out of seventy-five had blackheart, and many had, also, cavities. The other nine had neither blackheart nor cavities.

In Section 4, at a depth of 72–99 inches, none of the tubers had sprouted. They were wet, but free from mold. The great majority were solid. A few were affected with a soft, foul-smelling bacterial decay. Of twenty-five, cut immedately, twenty had large cavities, most of which had a black lining, and a few of the tubers had traces of blackheart in addition. After a few hours' exposure all twenty

had good cases of typical blackheart. The other five tubers lacked cavities, but upon exposure to the air they developed blackheart.

The remaining tubers from Section 4 were exposed to the air for twenty-four hours. By this time a considerable number were partly rotten. On many of them large areas of the surface were badly discolored (nearly black) and frequently slightly sunken. There was, also, considerable pitting and spotting resembling the injury produced by formaldehyde gas. Seventy-five additional tubers were cut. All had blackheart and many had, also, large cavities.

In Section 5 the tubers were very wet and there was a considerable quantity of a foul-smelling liquid in the bottom of the tank. The great majority of the tubers were still solid. A few were affected with bacterial decay. There was no mold. Twenty out of twenty-five tubers cut immediately had large black-lined cavities. Upon exposure to the air these tubers all developed blackheart. Two of the remaining five had each a large area of typical blackheart (also a cavity) when first cut. The other three were free from cavities and blackheart when first cut, but developed blackheart upon exposure to the air.

After twenty-four hours' exposure to the air the external appearance of the remaining tubers of this lot was decidedly superior to that of the tubers from Section 4. They were less discolored and less affected with rot. A considerable number were free from external blemishes. However, all had pronounced blackheart and many contained, also, cavities.

Tubers in this experiment were much more severely injured at the end of forty-six days than were tubers in the preceding experiment at the end of sixty-two days. This must be attributed, chiefly, to the higher temperature in the present experiment. Probably, the higher rate of respiration due to the greater age of the tubers was a minor factor.

The blackheart found among tubers in the open tanks in this experiment was like that produced in sealed jars, except that it was often accompanied by cavities which were already black-lined when the tubers were first taken out. The progressive change in color, from white thru pink to black, was exactly like that which takes place in tubers which have been asphyxiated in sealed jars.

SEVENTH TANK EXPERIMENT.

The seventh tank experiment was a particularly instructive one for two reasons, viz., (1) It was conducted in a regular potato cellar under conditions like those in which potatoes are often stored; and (2) It furnished a basis for the interpretation of the unexpected results obtained in the outdoor pit experiment described on page 356.

TABLE IV.— TEMPERATURE RECORDS: SEVENTH TANK EXPERIMENT AND OUTDOOR PIT EXPERIMENT.

TANK EXPERIMENT IN CELLAR.			OUT-DOOR PIT EXPERIMENT.				
Date.	Temperature.		Date.	Temperature of outside air.		Temperature inside pit.	
	Deg. F.	*Deg. C.*		*Deg. F.*	*Deg. C.*	*Deg. F.*	*Deg. C.*
Nov. 18....	42	5.5	Nov. 18....	37.5	3.1	39.5	4.2
Nov. 22....	43	6.1	Nov. 27....	53	11.7	42	5.5
Nov. 27....	45	7.2	Dec. 2....	35	1.7	42	5.5
Dec. 1.....	43	6.1	Dec. 11....	26	—3.3	42	5.5
Dec. 16.....	36	2.2	Dec. 18....	34	1.1	42	5.5
Jan. 3.....	41.5	5.3	Jan. 3.....	31	—0.5	42	5.5
Jan. 5.....	41	5	Jan. 12.....	33	0.5	41	5
Jan. 7.....	40.5	4.7	Jan. 19.....	22	—5.5	38	3.3
Jan. 12.....	40	5	Jan. 22.....	51	10.5	38	3.3
Jan. 18.....	37	2.8	Jan. 28.....	42	5.5	39	3.9
Jan. 22.....	41	5	Jan. 31.....	58	14.4	40	4.4
Jan. 26.....	42	5.5	Feb. 14....	9.5	—12.5	39.5	4.2
Feb. 14.....	34	1	Feb. 21....	10	—12.2	37	2.8
Feb. 17.....	35	1.7	Feb. 28....	17	—8.3	37	2.8
March 2...	34	1.1	March 7....	46	7.8	36.5	2.5
March 7...	36.5	2.5	March 11...	25	—3.5	36.5	2.5
March 10...	35	1.7	March 27...	39	3.9	36.5	2.5
March 25...	36	2.2	April 3....	41	5	37.5	3.1
March 27...	36	2.2	April 7....	39	3.9	38	3.3
April 25....	44	6.7	April 13....	42	5.5	39	3.9
May 9.....	48	8.8	April 24....	55	12.8	44	6.7
May 11.....	48.5	9.2	May 1....	60	15.5	47	8.3
May 19.....	49	9.4	May 5....	63	17.2	51	10.5
May 26.....	52	11.1	May 8....	72	22.2	53	10.5
.....	.....	.....	May 15....	.....	.....	56.5	12.5
.....	.....	.....	May 20....	64	17.8	56.5	12.5
.....	.....	.....	May 25....	72	22.2	56.5	12.5
.....	.....	.....	May 26....	71	21.7	57	12.8

Three 80-inch tanks (D, E and F) were put into the Station potato cellar and filled with potatoes on November 8, 1915. Each tank was separated into three sections in the usual manner. A Fahren-